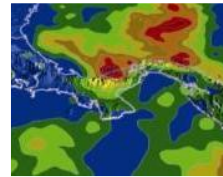
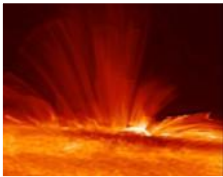




Lessons Learned from 30 Years in the Space Shuttle Program

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marshall



“Risky Business”

Space launch systems are inherently risky endeavors

- It takes a tremendous amount of energy to get to orbit
- Highly energetic systems must be designed, manufactured, assembled, and operated
- Launch environments are harsh
- Desire for high-performance often results in very complex designs with low margins
- Production rates are relatively low, yet often complex

The launch vehicle's basic mission is to deliver people and/or high dollar investments to orbit

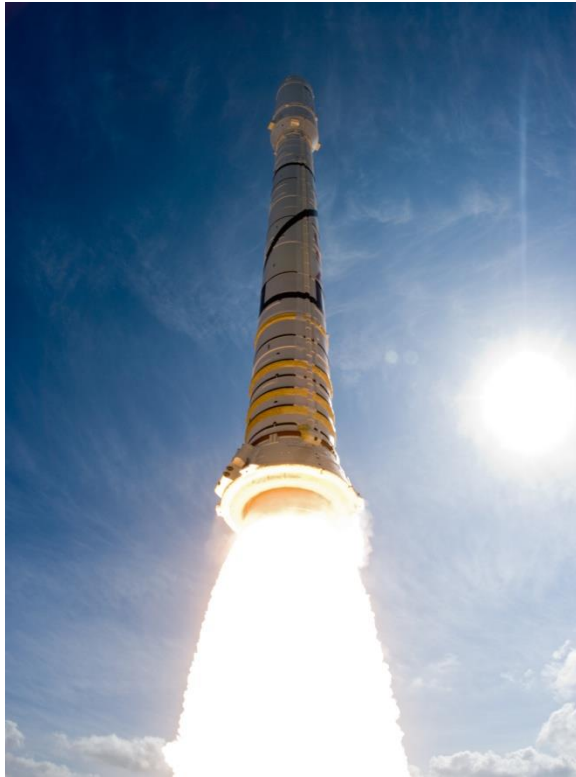
- The consequences of failure are significant



Managing Risks

“Risk comes from not knowing what you’re doing.”

Warren Buffett 1930- , American Investment Entrepreneur



Managing a “risky business” warrants careful attention to:

- identifying and characterizing risks
- mitigating risks to “acceptable levels”
- verifying the desired mitigations are in place
- monitoring performance to assure mitigations perform as expected over time

“Know Your Risks”

- **Identifying and characterizing the safety and mission success risks** associated with a space launch system **is no simple task.**
- There are many sources of these risks, spanning from:
 - the harsh environments they operate in
 - design complexities driven by needs for high-performance
 - complex interactions within the system and its external interfaces
 - hardware failure mechanisms
 - reliance on software to fly the vehicle
 - low manufacturing production rates coupled with the need for high-quality products



Thoughts from the Last 30 Years of the Space Shuttle Program

- **People are your most Important Resource** to assure Flight Safety And Mission Success. Value them.
- **Open Communication Should Be the Standard** that is embraced by the Highest Management to the Line Supervisor. Never tolerate Retribution for Speaking Up. If the King Has No Clothes, Tell Him.
- **Beware of Normalization of Deviance.**
- **Be Willing to Make a Decision.**

- **All Flight Rationale Should Contain These Elements:**
- Solid Technical Understanding
- Condition Relative to Experience Base
- Bounding Case Established
- Self-Limiting Aspect
- Margins Understood
- Assessment Based on Data, Testing, and Analysis
- Interactions with Other Elements/Conditions Addressed

Stay Humble – You are never as smart as you think you are

- **Invest early in good, multi-disciplined, structured brainstorming** about possible failure modes for each component. (FMEA/CIL and Hazards Analysis are great, established tools for doing this!) It will pay off.
- **Launch vehicles operate on the edge of technical feasibility and in a regime frequently beyond your engineering intuition. Pocketing**
- **Margin and fault tolerance** are essential when you design on the edge.
- **Test what you fly and fly what you test.** Test at the corners of the Box. (Challenger)
- **Resist Cutting Test Because of Budget Issues.**

- **Always seek out dissenting opinions. Beware of Group Think.**
- **Listen to your hardware.** It is always talking to you. (External Tank)
- **Major decision meetings** (Flight Readiness Reviews, Critical Design Reviews) need to be held face-to-face.
- **Reward people for speaking up.**

Communications and Making Good Decisions

- Challenge analyses, **especially** from models that are not anchored with actual empirical data. Have a good understanding of the assumptions in the models.
- **Listen** with an open mind. When you focus on the end answer, you tend to hear things only with an ear to confirm what you want that end answer to be (**Confirmation bias**).
- **Cheating Gravity is hard to do.** You do the best you can and make the best decisions that you possibly can, and sometimes you'll be wrong. Margin and fault tolerance. (STS-78 PSA)
- It is always better to *determine* the condition of a suspect component (via direct measurement or observation) than it is to *infer* its condition via indirect measurement or observation or, worse yet, analysis. (Columbia wing on-orbit)

Communications and Making Good Decisions

- Both Columbia and Challenger were brought down by **known problems** that were being managed, not by somebody missing something or some new failure mode. You must critically challenge MRs, problem reports, etc., and get them right!
- Guard against compartmentalization. **Don't be a bystander** and assume that somebody else who knows a lot more about the subject isn't worried about the question in your mind. Sometimes the sponsors are engaging in wishful thinking. **Be courageous** and ask what you think is the obvious question. Don't Check Your Brain at the Door.

Communications and Making Good Decisions

- When a technical matter is presented to you for decision, play it back to presenters in your own words.
- **Risk tolerance goes way up as a deadline or milestone approaches. Guard against it. Someone's life may be depending on it.**
- **Know your team.** Be there for them. Things at home affect how decisions are made.

Communications and Making Good Decisions

- **You're never as smart as you think you are.** If a team member (analyst, subsystem manager, chief engineer, etc.) habitually comes across as dead sure on technical matters, then they haven't learned this lesson yet.
- **Cost and schedule pressures are always present and real**, but don't let them box you into thinking that stand-down is not a real option. It is. Don't say, "Well, we have to do it this way or we can't fly." Sometimes you, indeed, **can't** fly.
- **Make sure your team is willing to speak up** and challenge technical presentations, no matter who is presenting. Speaking up is tough. (STS-112 FRR)

People



A Final Reminder

“A worker at KSC told me that they haven't heard any NASA managers admit to being at fault for the loss of Columbia. I cannot speak for others, but let me set my record straight: I am at fault. If you need a scapegoat, start with me. I had the opportunity and the information and I failed to make use of it. I don't know what an inquest or a court of law would say, but I stand condemned in the court of my own conscience to be guilty of not preventing the Columbia disaster. We could discuss the particulars: inattention, incompetence, distraction, lack of conviction, lack of understanding, a lack of backbone, laziness. The bottom line is that I failed to understand what I was being told; I failed to stand up and be counted. Therefore, look no further; I am guilty of allowing Columbia to crash.

As you consider continuing in this program, or any other high risk program, weigh the cost. You, too, could be convicted in the court of your conscience if you are ever party to cutting corners, believing something life and death is not your responsibility, or simply not paying attention. The penalty is heavy, you can never completely repay it.

Do good work. Pay attention. Question everything. Be thorough. Don't end up with regrets.”

---Wayne Hale